GROWTH OF JUVENILE AMERICAN LOBSTERS IN SEMIOPEN AND CLOSED CULTURE SYSTEMS USING FORMULATED DIETS

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ABSTRACT.— Growth of juvenile American lobsters, *Homarus americanus*, raised in four semiopen culture systems, with daily water exchange rates ranging from 29 percent to 3.3 percent, was compared with growth in a completely closed system. Animals were fed a formulated pelleted ration, water quality factors were measured daily, and changes in concentration of nitrate, orthophosphate, and total organic carbon were monitored. Results of two 90-day trials indicate that growth increased in the system with the lower water exchange rates. Maximum growth occurred in the closed system.

Interest in commercial culture of the American lobster, *Homarus americanus*, has increased because of high consumer demand and declining natural fisheries. Dow (1980) indicates that this decline is probably due to overexploitation of the lobster. He states that during the period from 1950 to 1976, inshore landings of lobsters from Newfoundland to New York decreased from 33,000 to 30,000 metric tons and the number of traps used increased from 240,000 to 520,000. Other data indicate that in some areas annual trap success has also declined from 225 pounds per trap in 1889 to 17 pounds per trap in 1970 (John T. Hughes, pers. comm.).

The American lobster is one of four marine species given "high priority" status for aquaculture by the U.S. National Oceanographic and Atmospheric Administration because it meets several requirements for commercial production of aquatic species (Glude 1977). These criteria include adequate consumer demand, high profit potential, ability to complete the life cycle in captivity, high food conversion efficiency, and resistance to disease (Cobb 1976). The economic potential of lobster culture depends on satisfaction of these factors, plus the development of efficient larval rearing and grow-out systems, production of inexpensive diets, and determination and maintenance of optimum culture environments. The last two factors (formulated diets and determination of optimum conditions) are studied in this experiment.

Numerous studies have been done on basic nutritional requirements of crustaceans (Gallagher et al. 1979, Winget et al. 1976, Castell and Covey 1976). Most researchers agree that formulated diets must replace expensive natural rations for lobster culture to be economically feasible (Van Olst et al. 1980). Conklin et al. (1975) define nutritional requirements for lobsters and report initial development of pelleted rations. The formulation of diets in pellet form is desirable in aquaculture because of ease in production, handling, and feeding (Conklin 1980). Goldblatt et al. (1978) and Infanger et al. (1980) indicate that pelleted rations may lose nutritional quality through vitamin leaching when exposed to culture water. This makes most diets developed thus far unacceptable for lobster culture.

Culture systems are usually classified as open, semiopen, or closed. Wheaton (1977) described open systems as production in a natural body of water with few modifications, semiopen systems as those where water is taken from a natural source, passed through the system once and discarded, and closed systems as those where water is placed within the system and is rarely if ever replaced. The economic production of lobsters is restricted to semiopen and closed systems because natural water temperatures in most areas are below optimal growth temperatures and must be heated to accelerate animal growth.

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Many factors have been used in comparing semiopen and closed systems for culture of marine organisms (King 1973). One important contrast for lobster culture may be differences in growth rates between systems. It is unknown if juvenile lobsters will grow faster in a particular type of system. The purpose of this experiment was to compare lobster growth in five different culture environments ranging from semiopen systems (with four different water exchange rates) to closed systems. Animals in all systems were fed the same formulated diet.

Materials and Methods

Four semiopen systems and one closed system were established in separate 300:1 tanks. Water was removed from each semiopen system and replaced at different intervals, thereby producing daily water exchange rates of 29 percent in system I, 13 percent in system II, 7.4 percent in system III, and 3.3 percent in system IV. Water in system V remained unchanged during the experiment except for addition of fresh water to compensate for evaporation. A 10 cm thick undergravel filter in each tank provided filtration and a substrate for nitrifying bacteria.

Culture water was synthetic seawater similar to that described by Spotte (1970) for large marine aquaria. It was mixed in 1200 liter quantities for use in the experiment.

Forty-eight juvenile lobsters were tested in each culture system. Cages in each tank isolated animals, which allowed monitoring of the growth rate of each animal throughout the experiment.

Two 90-day trials were conducted (trial 1 and trial 2). Growth was determined by measuring animal length from eye socket to posterior margin of the carapace along the dorsal midline. Growth of animals between trials could not be compared because lobsters for each trial were hatched from two different females. Comparisons were made between systems within each trial.

Test animals were fed a pelleted diet similar to those described by Infanger et al. (1980). The pellets were produced using a Wenger extruder (model X-5), then sealed in plastic bags and stored at −18 C. Lobsters were fed daily in excess of what could be consumed during the 24-hour period. Food remaining from the previous day was removed before feeding a fresh pellet.

Water quality was monitored daily in each trial by testing salinity, pH, temperature, dissolved oxygen, and nitrite. All factors, with the exception of nitrite, were measured directly using the appropriate meter. Nitrite was recorded as percent transmittance, using a Bausch and Lomb Spectronic 20 (Spotte 1970).

Results of water quality measurements were compared with optimum levels described for lobster culture (Van Olst et al. 1980). These optimum levels included a temperature range between 20.0 and 22.0 C, 30.0 ppt salinity, 6.4 mg/l dissolved oxygen, a pH of 8.0, and nitrite levels less than 10.0 mg/l. Spotte (1973) recommends nitrite levels less than 0.1 mg/l for large marine aquariums. Because nitrite is a potentially toxic waste compound, the lower concentration of 0.1 mg/l or less was considered optimum. It was determined through use of a standard nitrite solution that a transmittance of 74 percent or higher indicated concentrations lower than this level.

Additional tests were performed on water taken from the first trial by the certified Brigham Young University Environmental Analysis Laboratory. Samples were tested for two elements (copper and iron) and for three compounds (nitrate, orthophosphate, and total organic carbon). These substances may be important toxins or nutrients in culture systems that may strongly affect animal growth (Spotte 1979, Wheaton 1977). Two samples were tested: one sample was freshly made seawater, and the second was the same water taken from system V after the 90-day culture period.

Three compounds tested in the first trial (nitrate, orthophosphate, and total organic carbon) were tested more extensively in the second trial from all five water systems. Samples were taken at the beginning of the culture period and again prior to a water change in that particular system. For example, an initial sample was taken on day 1 from each system and again on day 4 from system I, on day 7 from system II, on day 14 from system III, and on day 30 from system IV. This testing was duplicated twice from

each semiopen system (series A and B). Water samples from system V were taken for analysis on days 1, 30, 60, and 90.

RESULTS

Results of juvenile lobster growth experiments from both trials include: (1) water quality, (2) detailed water analysis, and (3) growth and survival.

Water Quality

Water quality was monitored by daily measurement of temperature, salinity, pH, and nitrite. Temperature averaged 20.0 and 21.0 C, mean salinity was 31.0 and 32.0 ppt, pH averaged 8.1, and mean nitrite transmittance was 91.5 and 94.3 percent in trial 1 and trial 2 respectively.

Dissolved oxygen in trial 1 had a mean concentration of 5.5 mg/l. This value remained constant throughout the trial and represents the saturation level at ambient salinity, temperature, and atmospheric pressure. Dissolved oxygen was not tested in trial 2.

Detailed Water Analysis

In comparing 90-day-old water with freshly made synthetic water in trial 1, levels of iron decreased, whereas concentrations of copper, nitrate, orthophosphate, and total organic carbon increased (Table 1). The last three compounds were tested more extensively in trial 2 and compared with concentrations in all five culture systems.

TABLE 1. Water comparisons: Trial 1.

Tests		New[a]	Old[b]	Normal levels
Copper as Cu	(ug/l)	36	49	60[c]
Iron as Fe	(ug/l)	92	66	300[c]
Nitrate as N	(mg/l)	0.46	2.15	20[c]
Phos-Ortho as P	(mg/l)	0.23	2.07	1.0 (ug/l)[d]
Total organic carbon	(mg/l)	16.66	19.60	6.0[d]

[a]Freshly made synthetic seawater
[b]Synthetic seawater after 90 days
[c]From Van Olst et al. (1980)
[d]From Spotte (1979) for marine aquaria

Nitrate

Nitrate concentrations increased with the age of culture water within each of the five systems (Fig. 1). Initial levels were below 1.0 mg/l with the exception of a sample from system I that started at 1.3 mg/l. Final levels ranged from 0.4 mg/l in system I after 4 days to 11.2 mg/l in system V after 90 days. The second set of duplicate tests (series B) showed greater increases of nitrate than the first set of tests (series A) in each semiopen system. This probably occurred because samples for the second series were taken later in the culture period, when biological filters were more efficient in converting ammonia to nitrate.

Nitrate concentration increased inversely with the amount of water replacement in the four semiopen systems. Final concentrations from the second duplicate series were 1.4 mg/l in system I after 4 days, 1.9 mg/l in system II after 7 days, 5.5 mg/l in system III after 14 days, and 10.5 mg/l in system IV after 30 days.

Results from system V showed nitrate increases over the 90-day culture period, when concentration increased from 0.46 mg/l on day 1 to 11.2 mg/l by day 90.

Orthophosphate

Orthophosphate increased with the age of water within each system (Fig. 2). Initial levels ranged from 0.23 mg/l to 0.41 mg/l, whereas final concentrations ranged between 0.67 mg/l in system I to 3.40 mg/l in system

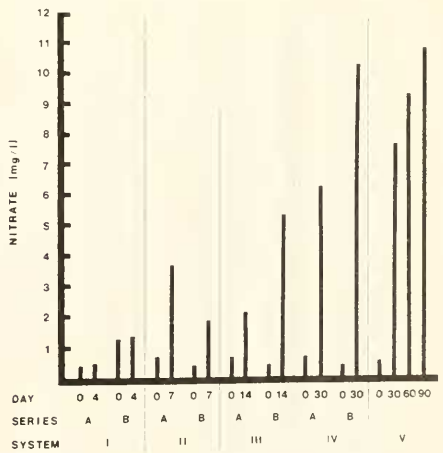

Fig. 1. Nitrate concentration comparisons for systems from trial 2.

V. These levels are greater than concentrations found in natural seawater, but compare favorably with concentrations reported in large marine aquaria (Spotte 1979).

Total Organic Carbon

Levels of total organic carbon (TOC) increased with the age of water within each system (Fig. 3). This increase can be seen in system V, which started at 16.7 mg/l on day 1 and increased to 21.9 mg/l by day 30, to 27.8 mg/l by day 60, and to 28.7 mg/l by day 90.

TOC concentration increases did not correlate with water exchange when systems were compared with each other. The greatest differences occurred in system III, which increased from 14.7 mg/l to 37.5 mg/l in 14 days. The highest final concentration (24.1 mg/l) occurred in system I after only four days.

Growth and Survival

Results indicate that culture systems do affect juvenile lobster growth. In both trials, animals in system V had faster growth rates than any other system (Fig. 4). They were significantly larger ($p = .05$) than in systems I, II, and III in trial 1 and systems I and II in trial 2 (standard Students t-test). Growth in both trials, with the exception of system II in trial 2, have an inverse relationship with daily water exchange rates even though all differences were not significant.

Survival ranged from 46.0 percent to 73.0 percent, averaging 57.2 percent in trial 1, and from 50.0 percent to 90.0 percent, averaging 72.2 percent in trial 2 (Fig. 5). No clear patterns resulted from either trial. System III had the best survival in trial 2 and the most deaths in trial 1.

Discussion

Results indicate that water exchange affected juvenile lobster growth rates when water quality factors (temperature, salinity, pH, dissolved oxygen, and nitrate) were maintained within limits suggested by Van Olst et al. (1980) for lobster culture and by Spotte (1973) for marine aquaria. Growth rates increased in both trials with decreasing water exchange, with the best growth occurring in the closed systems. Reasons for this are unclear, but differences may be partially explained by changes in water chemistry.

Wheaton (1977) indicates that water chemistry will change in culture environments depending on the length of time water remains in the system. Sources of the three compounds tested in trial 2 (nitrate, orthophosphate, and total organic carbon) include leached nutrients from unstable diets and waste products from animal metabolism. Copper and iron were not tested in trial 2 because concentrations did not change greatly in trial 1.

Increase of nitrate in closed systems is well documented (Liao and Mayo 1972, King

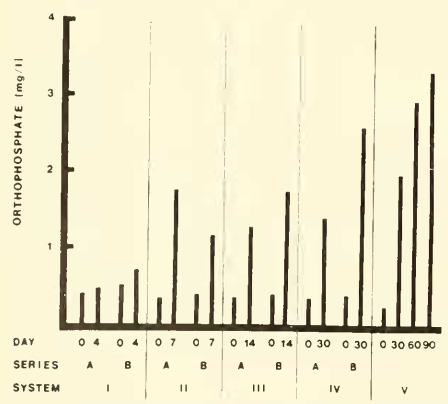

Fig. 2. Orthophosphate concentration comparisons for systems from trial 2.

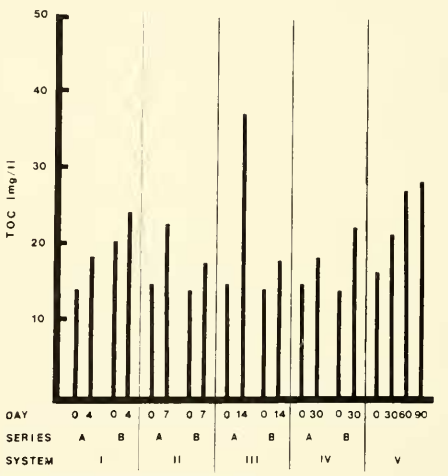

Fig. 3. Total organic carbon concentration comparisons for systems from trial 2.

1973). Toxicity levels of nitrate are unknown for most species, but Van Olst et al. (1980) suggests 500 mg/l as the maximum concentration desirable for lobster culture. Data from this experiment show increases of nitrate relative to the age of the water. Levels of nitrate for all systems (highest concentration was 11.2 mg/l in system V) were well below 500 mg/l, which probably indicates that nitrate was not an important factor in this experiment. Nitrate may become toxic, however, in closed systems designed for very long periods between water changes.

Wheaton (1977) states that most soluble phosphate in aquatic systems is in the form of inorganic orthophosphate. It is excreted by culture animals and also results from autolysis and subsequent mineralization of damaged or dead cells by heterotrophic bacteria (Spotte 1979). Goldblatt et al. (1978) also found small amounts leaching from gluten-based diets similar to the ration used in this experiment. Orthophosphate is removed from aquatic systems by marine algae and by air stripping when the compound is absorbed onto the surface of air bubbles that rise to the surface. Results indicate that concentrations do increase in closed systems. Spotte (1979) states, however, that levels eventually reach equilibrium because of air stripping. Toxic concentrations have not been reported for lobster culture, but increased levels will stimulate algae growth in marine systems (Wheaton 1977). This algae may act as a dietary supplement for culture animals and may account for some of the increased growth in systems with low water exchange.

Organic carbon results from animal wastes and extracellular products of aquatic plants (Spotte 1979). TOC levels may also include water soluble nutrients (vitamins, carbohydrates, and proteins) that leach from unstable pelleted rations. TOC, like orthophosphate, is removed from water systems by air stripping (Spotte 1979). This may account for the random concentrations occurring between systems. No toxic levels have been reported for lobster culture.

All TOC levels reported were at least three times higher than those reported in large marine aquaria (Spotte 1979). This discrepancy occurred because of a difference in analysis procedure. Spotte used wet oxidation, whereas samples from this experiment were analyzed using dry combustion. Williams (1975) reported three- to fourfold differences between these two techniques testing the same water sample.

Mortality in most systems of both trials was very high. This was probably not a result of the water system, but occurred because of low nutritional value of the diet. High mortality has been an inherent problem in lobster culture with the use of formulated diets (Conklin 1980). Recently, rations have been developed that consistently reduce mortalities to less than 10 percent (Rex Infanger and Roger Mickelsen, unpubl. data). This is a significant advancement because low

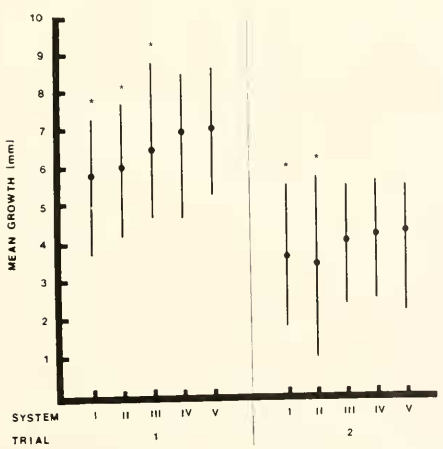

Fig. 4. Means and ranges of growth for trials 1 and 2. ° indicates significantly less growth compared with system V, using the standard Student t-test ($p = .05$).

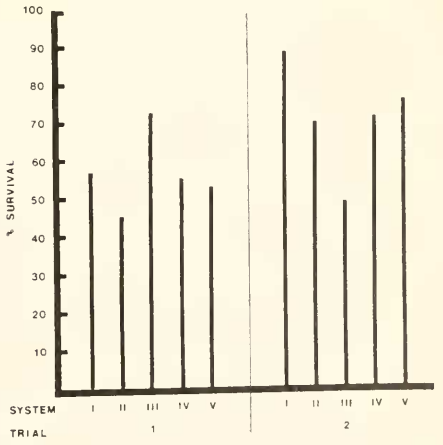

Fig. 5. Survival of juvenile lobsters from trials 1 and 2 after 90 days.

mortality and accelerated growth are necessary for lobster culture to be feasible.

Closed systems provide many advantages over semiopen systems, including lower energy costs in heating and maintaining water temperature, greater efficiency in maintaining ideal culture conditions (salinity, pH, and dissolved oxygen), and fewer disease problems (King 1973). It can be concluded from this experiment that the closed systems tested also produce better growth of juvenile lobsters.

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